ABERRATION PROBLEMS.[1]

EVERYBODY knows that to shoot a bird on the wing you must aim in front of it. Every one will readily admit that to hit a squatting rabbit from a moving train you must aim behind it.

These are examples of what may be called "aberration" from the sender's point of view, from the point of view of the source. And the aberration, or needful divergence between the point aimed at and the thing hit, has opposite sign in the two cases—the case when receiver is moving, and the case when source is moving. Hence, if both be moving, it is possible for the two aberrations to neutralize each other. So to hit a rabbit running alongside the train, you must aim straight at it.

If there were no air that is all simple enough. But every rifleman knows to his cost that though he fixes both himself and his target tightly to the ground, so as to destroy all aberration proper, yet a current of air is very competent to introduce a kind of spurious aberration of its own, which may be called windage; and that he must not aim at the target if he wants to hit it, but must aim a little in the eye of the wind.

So much from the shooter's point of view. Now attend to the point of view of the target.

Consider it made of soft enough material to be completely penetrated by the bullet, leaving a longish hole wherever struck. A person behind the target, whom we may call a marker, by applying his eye to the hole immediately after a hit, may be able to look through it at the shooter, and thereby to spot the successful man. I know that this is not precisely the function of an ordinary marker, but it is more complete than his ordinary function. All he does usually is to signal an impersonal hit; someone else has to record the identity of the shooter. I am rather assuming a volley of shots, and that the marker has to allocate the hits to their respective sources by means of the holes made in the target.

Well, will he do it correctly? assuming, of course, that he can do so if everything is stationary, and ignoring all curvature of path, whether vertical or horizontal curvature. If you think it over you will perceive that a wind will not prevent his doing it correctly; the line of hole will point to the shooter along the path of his bullet, though it will not point along his line of aim. Also, if the shots are fired from a moving ship, the line of hole in a stationary target will point to the position the gun occupied at the instant the shot was fired, though it may have moved since then. In neither of these cases (moving medium and moving source) will there be any aberration error.

But if the *target* is in motion, on an armoured train for instance, then the marker will be at fault. The hole will not point to the man who fired the shot, but to an individual ahead of him. The source will appear to be displaced in the direction of the observer's motion. This is common aberration. It is the simplest thing in the world. The easiest illustration of it is that when you run through a vertical shower, you tilt your umbrella forward; or, if you have not got one, the drops hit you in the face; more accurately, your face as you run forward hits the drops. So the shower appears to come from a cloud ahead of you, instead of from one overhead.

We have thus three motions to consider, that of the source, of the receiver, and of the medium; and of these only motion of receiver is able to cause an aberrational error in fixing the position of the source.

So far we have attended to the case of projectiles, with the object of leading up to light. But light does not consist of projectiles, it consists of waves; and with waves matters are a little different. Waves crawl through a medium at their own definite pace; they cannot be *flung* forwards or sideways by a moving source; they do not move by reason of an initial momentum which they are gradually expending, as shots do; their motion is more analogous to that of a bird or other self-propelling animal than it is to that of a shot. The motion of a wave in a moving medium may be likened to that of a rowing boat on a river. It crawls forward with the water, and it drifts with the water; its resultant motion is compounded of the two, but it has nothing to do with the motion of its source. A shot from a passing steamer retains the motion of the steamer as well as that given it by the powder. It is projected therefore in a slant direction. A boat lowered from the side of a passing steamer, and rowing off, retains none of the motion of its source; it is not projected, it is self-propelled. That is like the case of a wave.

The diagram illustrates the difference. Fig. 1 shows a moving cannon or machine-gun, moving with the arrow, and firing a succession of shots which share the motion of the cannon as well as their own, and so travel slant. The shot fired from position 1 has reached A, that fired from the position 2 has reached B, and that fired from position 3 has reached C by the time the fourth shot is fired at D. The line ABCD is a prolongation of the axis of the gun; it is the line of aim, but it is not the line of fire; all the shots are travelling aslant this line, as shown by the arrows. There are thus two directions to be distinguished. There is the row of successive shots, and there is the path of any one shot. These two directions enclose an angle. It may be called an aberration angle, because it is due to the motion of the source, but it need not give rise to any aberration. True direction may still be perceived from the point of view of the receiver. Attend to the target. The first shot is supposed to be entering at A, and if the target is stationary will leave it at Y. A marker looking along YA will see the position whence the shot was fired. This may be likened to a stationary observer looking at a moving star. He sees it where and as it was when the light started on its long journey. He does not see its present position, but there is no reason why he should. He does not see its physical state or anything as it is now. There is no aberration caused by motion of source.

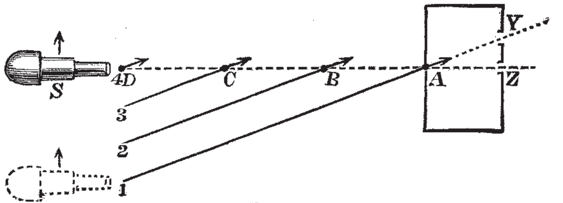

FIG. 1.

But now let the receiver be moving at same pace as the gun, as when two grappled ships are firing into each other. The motion of the target carries the point Y forward, and the shot A leaves it at Z, because Z is carried to where Y was. So in that case the marker looking along ZA will see the gun, not as it was when firing, but as it is at the present moment; and he will see likewise the row of shots making straight for him. This is like an observer looking at a terrestrial object. Motion of the earth does not disturb ordinary vision.

Fig. 2 shows as nearly the same sort of thing as possible for the case of emitted waves. The tube is a source emitting a succession of disturbances without momentum. ABCD may be thought of as horizontally flying birds, or as crests of waves; or they may even be thought of as bullets, if the gun stands still every time it fires, and only moves between whiles.

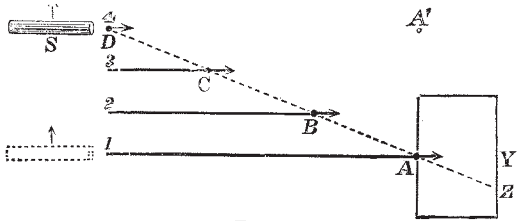

FIG. 2.

The line ABCD is now neither the line of fire nor the line of aim: it is simply the locus of disturbances emitted from the successive positions 1 2 3 4.

A stationary target will be penetrated in the direction AY, and this line will point out the correct position of the source when the received disturbance started. If the target moves, a disturbance entering at A may leave it at Z, or at any other point according to its rate of motion; the line ZA does not point to the source, and so there will be aberration when the target moves. Otherwise there would be none.

Now Fig. 2 also represents a parallel beam of light travelling from a moving source, and entering a telescope or the eye of an observer. The beam lies along ABCD, but this is not the direction of vision. The direction of vision to a stationary observer is determined not by the locus of successive waves, but by the path of each wave. A ray may be defined as the path of a labelled disturbance. The line of vision is YA1, and coincides with the line of aim; which in the projectile case (Fig. 1) it did not.

---

[1] A lecture on "The Motion of the Ether near the Earth," by Dr. Oliver Lodge, at the Royal Institution, Friday evening, April 1, 1892.

The case of a revolving lighthouse, emitting long parallel beams of light and brandishing them rapidly round, is rather interesting. Fig. 3 may assist the thinking out of this case. Successive disturbances A,B,C,D, lie along a spiral curve, the spiral of Archimedes; and this is the shape of the beams as seen illuminating the dust particles, though the pitch of the spiral is too gigantic to be distinguished from a straight line. At first sight it might seem as if an eye looking along those curved beams would see the lighthouse slightly out of its true position; but it is not so. The true rays or actual paths of each disturbance are truly radial; they do not coincide with the apparent beam. An eye looking at the source will not look tangentially along the beam, but will look along AS, and will see the source in its true position. It would be otherwise for the case of projectiles from a revolving turret.

Thus, neither translation of star nor rotation of sun can affect direction. There is no aberration so long as the receiver is stationary.

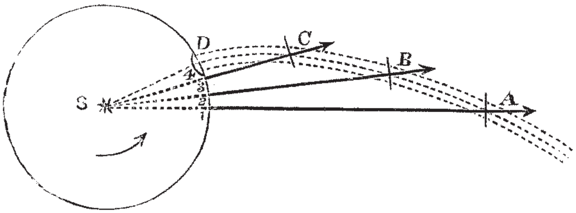

FIG. 3.

But what about a wind, or streaming of the medium past source and receiver, both stationary? Look at Fig. 1 again. Suppose a row of stationary cannon firing shots, which get blown by a cross wind along the slant 1AY (neglecting the curvature of path which would really exist): still the hole in the target fixes the gun's true position, the marker looking along YA sees the gun which fired the shot. There is no true deviation from the point of view of the receiver, although the shots are blown aside and the target is not hit by the particular gun aimed at it. With a moving cannon, combined with an opposing wind, Fig. 1 would become very like Fig. 2.

(N.B.—The actual case, even without complication of spinning, &c., but merely with the curved path caused by steady wind-pressure, is not so simple, and there would really be an aberration or apparent displacement of the source towards the wind's eye: an apparent exaggeration of the effect of wind as shown in the diagram.)

In Fig. 2 the result of a wind is much the same, though the details are rather different. The medium is supposed to be drifting down across the field opposite to the arrows. The source is stationary at S. The arrows show the direction of waves *in the medium*; the dotted slant line shows their resultant direction. A wave centre drifts from D to 1 in the same time as the disturbance reaches A, travelling down the slant line DA. The angle between dotted and full lines is the angle between ray and wave movement. Now, *if the motion of the medium inside the receiver is the same as it is outside*, the wave will pass straight on along the slant to Z, and the true direction of the source is fixed. But if the medium inside the target or telescope is stationary, the wave will cease to drift as soon as it gets inside, under cover as it were; it will proceed along the path it has been really pursuing *in the medium* all the time, and make its exit at Y. In this latter case, of different motion of the medium inside and outside the telescope, the apparent direction, such as YA, is not the true direction of the source. *The ray is in fact bent where it enters the differently-moving medium* (as shown in Fig. 4).

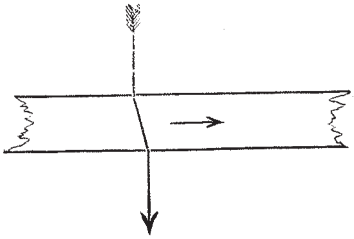

FIG. 4.

A slower moving stratum bends an oblique ray (slanting with the motion) in the same direction as a denser medium does. A quicker stratum bends it oppositely. If a medium is both denser and quicker moving, it is possible for the two bendings to be equal and opposite, and thus for a ray to go on straight. Parenthetically I may say that this is precisely what happens, on Fresnel's theory, down the axis of a water-filled telescope exposed to the general terrestrial ether drift.

In a moving medium waves do not advance in their normal direction, they advance slantways. The direction of their advance is properly called a ray. The ray does not coincide with the wave-normal in a moving medium.

All this is well shown in fig. 5.

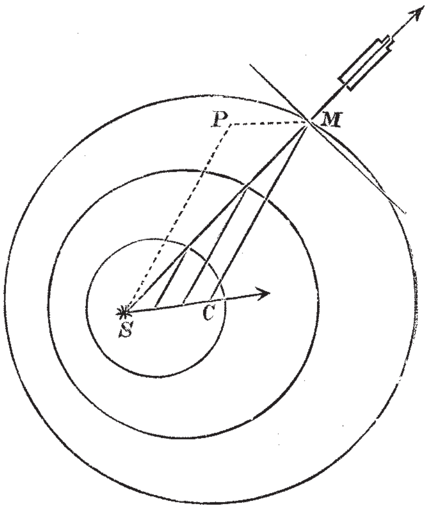

FIG. 5.

S is a stationary source emitting successive waves, which drift as spheres to the right. The wave which has reached M has its centre at C, and CM is its normal; but the disturbance, M, has really travelled along SM, which is therefore the ray. It has advanced as a wave from S to P, and has drifted from P to M. Disturbances subsequently emitted are found along the ray, precisely as in Fig. 2. A stationary telescope receiving the light will point straight at S. A mirror, M, intended to reflect the light straight back must be set normal to the ray, not tangential to the wave front.

The diagram also equally represents the case of a moving source in a stationary medium. The source, starting at C, has moved to S, emitting waves as it went, which waves as emitted spread out as simple spheres from the then position of source as centre. Wave-normal and ray now coincide: SM is not a ray, but only the locus of successive disturbances. A stationary telescope will look not at S, but along MC to the point where the source was when it emitted the wave M; a moving telescope, if moving at same rate as source, will look at S. Hence SM is sometimes called the *apparent* ray. The angle SMC is the aberration angle.

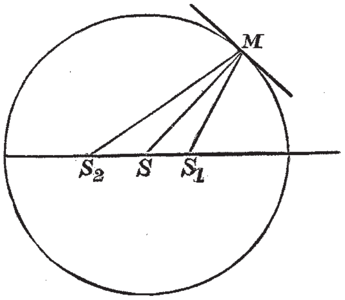

FIG. 6.

Fig. 6 shows normal reflection for the case of a moving source.

The mirror M reflects light received from S_1 to a point S_2, just in time to catch the source there; as it travels steadily to the left.

Parenthetically I may say that the time taken on the double journey, S_1MS_2, is not quite the same as the double journey SMS when all is stationary, and that this is the principle of Michelson's great experiment referred to below.

For the rest of the lecture I am going to call the medium which conveys light, "ether" simply. Every one knows that ether is the light-conveying medium, however little else they know about the properties of that tremendously important material.

We have arrived at this: that a uniform ether stream all through space causes no aberration, no error in fixing direction. It blows the waves along, but it does not disturb the line of vision.

Stellar aberration exists, but it depends on motion of observer, and on motion of observer only. Etherial motion has no effect upon it, and when the observer is stationary with respect to object, as he is when using a terrestrial telescope, there is no aberration at all.

Surveying operations are not rendered the least inaccurate by the existence of a universal etherial drift; and they therefore afford no means of detecting it.

But observe that everything depends on the etherial motion being uniform everywhere, inside as well as outside the telescope, and along the whole path of the ray. If stationary anywhere it must be stationary altogether. There must be no boundary between stationary and moving ether, no plane of slip, no quicker motion even in some regions than in others. For (referring back to the remarks preceding Fig. 4) if the ether in receiver is stagnant while outside it is moving, a wave which has advanced and drifted as far as the telescope will cease to drift as soon as it gets inside, but will advance simply along the wave-normal; and in general at the boundary of any such change of motion a ray will be bent, and an observer looking along the ray will see the source not in its true position, not even in the apparent position appropriate to his own motion, but lagging behind that position.

Such an aberration as this, a lag or negative aberration, has never yet been observed; but if there is any slip between layers of ether, if the earth carries any ether with it, or if the ether being in motion at all is not equally in motion everywhere throughout every transparent substance, then such a lag or negative aberration must occur: in precise proportion to the amount of the carriage of ether by moving bodies.

On the other hand, if the ether behaves as a perfectly frictionless inviscid fluid, or if for any other reason there is no rub between it and moving matter, so that the earth carries no ether with it at all, then all rays will be straight, aberration will have its simple and well-known value, and we shall be living in a virtual ether stream of 19 miles a second, by reason of the orbital motion of the earth.

It may be difficult to imagine that a great mass like the earth can rush at this tremendous pace through a medium without disturbing it. It is not possible for an ordinary sphere in an ordinary fluid. At the surface of such a sphere there is a viscous drag, and a spinning motion diffuses out thence through the fluid so that the energy of the moving body is gradually dissipated. The persistence of terrestrial and planetary motions shows that etherial viscosity, if existent, is small; or at least that the amount of energy thus got rid of is a very small fraction of the whole. But there is nothing to show that an appreciable layer of ether may not adhere to the earth and travel with it, even though the force acting on it be but small.

This, then, is the question before us:—

Does the earth drag some ether with it? or does it slip through the ether with perfect freedom? (never mind the earth's atmosphere: the part it plays is not important).

In other words, is the ether wholly or partially stagnant[1] near the earth, or is it streaming past us with the opposite of the full terrestrial velocity of nineteen miles a second? Surely if we are living in an ether stream of this rapidity we ought to be able to detect some evidence of its existence.

It is not so easy a thing to detect as you would imagine. We have seen that it produces no deviation or error in direction. Neither does it cause any change of colour or Doppler effect; that is, no shift of lines in spectrum. No steady wind can affect pitch, simply because it cannot blow waves to your ear more quickly than they are emitted. It hurries them along, but it lengthens them in the same proportion, and the result is that they arrive at the proper frequency. The precise effects of motion on pitch are summarized in the following table:—

Changes of Frequency due to Motion.

Source approaching shortens waves.

Receiver approaching alters relative velocity.

Medium flowing alters both wave-length and velocity in exactly compensatory manner.

What other phenomena may possibly result from motion? Here is a list:—

Phenomena resulting from Motion.

(1) Change or apparent change in direction; observed by telescope, and called aberration.

(2) Change or apparent change in frequency; observed by spectroscope, and called Doppler effect.

(3) Change or apparent change in time of journey; observed by lag of phase or shift of interference fringes.

(4) Change or apparent change in intensity; observed by energy received by thermopile.

Motion of either source or receiver can alter frequency, motion of receiver can alter apparent direction, motion of the medium can do neither; but surely it can hurry a wave so as to make it arrive out of phase with another wave arriving by a different path, and thus produce or modify interference effects.

Or again it may carry the waves down stream more plentifully than up stream, and thus act on a pair of thermopiles, arranged fore and aft at equal distances from a source, with unequal intensity.

And again, perhaps the laws of reflection and refraction in a moving medium are not the same as they are if it be at rest. Then, moreover, there is double refraction, colours of thin plates and thick plates, polarization angle, rotation of the plane of polarization; all sorts of optical phenomena.

It may be, perhaps, that in empty space the effect of an ether drift is difficult to detect, but will not the presence of dense matter make it easier? Consider No. 3 of the phenomena tabulated above.

I expect that everyone here understands interference, but I may just briefly say that two similar sets of waves "interfere" whenever and wherever the crests of one set coincide with and obliterate the troughs of the other set. Light advances in any given direction when crests in that direction are able to remain crests, and troughs to remain troughs. But if we contrive to split a beam of light into two halves, to send them round by different paths, and make them meet again, there is no guarantee that crest will meet crest and trough trough; it may be just the other way in some places, and wherever that opposition of phase occurs there there will be local obliteration or "interference." Two reunited half-beams of light may thus produce local stripes of darkness, and these stripes are called interference bands.

If I can I will produce actual interference of light on the screen, but the experiment is a difficult one to make visible at a distance, partly because the stripes or bands of darkness are usually very narrow. I have not seen it attempted before. [Very visible bands were formed on screen by three mirrors, one of them semi-transparent, arranged as in Fig. 7.]

Now a most interesting and important, and I think now well-known, experiment of Fizeau proves quite simply and definitely that if light be sent along a stream of water, travelling inside the water as a transparent medium, it will go quicker with the current than against it. You may say that is only natural; a wind helps sound along one way and retards it the opposite way. Yes, but then sound travels in air, and wind is a bodily transfer of air, hence, of course, it gives the sound a ride; whereas light does not really travel in water, but always in ether. It is by no means obvious whether a stream of water can help or hinder it. Experiment decides, however, and answers in the affirmative. It helps it along with just about half the speed of the water; not with the whole speed, which is curious and important, and really means that the moving water has no effect whatever on the ether of space, though it would take too long to make clear how this comes about. Suffice for present purposes the fact that the velocity of light inside moving water, and therefore presumably inside all transparent matter, is altered by motion of that matter.

---

[1] The word "stationary" is ambiguous. I propose to use "stagnant," as meaning stationary with respect to the earth, *i.e.* as opposed to stationary in space.

Does not this fact afford an easy way of detecting a motion of the earth through the ether? Here on the table is water travelling along 19 miles a second. Send a beam of light through it one way and it will be hurried; its velocity, instead of being 140,000 miles a second, will be 140,009 miles. Send a beam of light the other way, and its velocity will be 139,991; just as much less. Bring these two beams together; surely some of their wave-lengths will interfere. M. Hoek, Astronomer at Utrecht, tried the experiment in this very form; here is a diagram of his apparatus (Fig. 8). Babinet had tried another form of the experiment previously. Hoek expected to see interference bands, from the two half-beams which had traversed the water, one in the direction of the earth's motion and the other against it. But no interference bands were seen. The experiment gave a negative result.

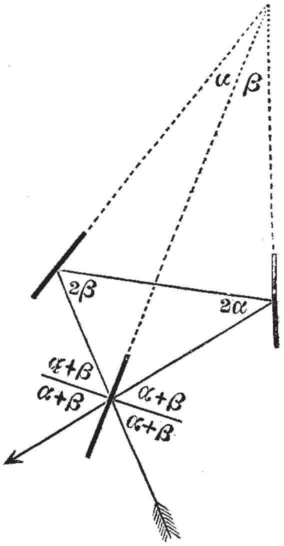

FIG. 7.—Plan of interference kaleidoscope.

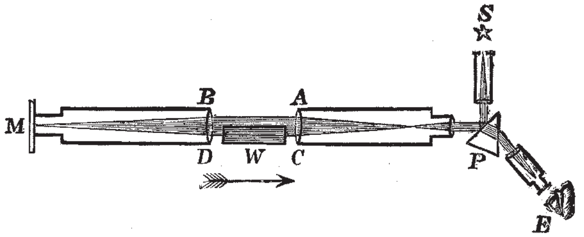

FIG. 8.

An experiment, however, in which nothing is seen is never a very satisfactory form of a negative experiment; it is, as Mascart calls it, "doubly negative," and we require some guarantee that the condition was right for seeing what might really have been in some sort there. Hence Mascart and Jamin's modification of the experiment is preferable (Fig. 9). The thing now looked for is a shift of already existing interference bands, when the above apparatus is turned so as to have different aspects with respect to the earth's motion; but no shift was seen.

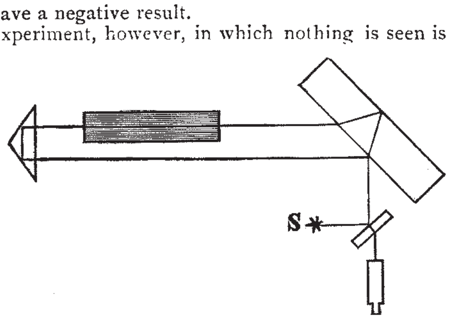

FIG. 9.

Interference methods all fail to display any trace of relative motion between earth and ether.

Try other phenomena then. Try refraction. The index of refraction of glass is known to depend on the ratio of the speed of light outside, to the speed inside, the glass. If then the ether be streaming through glass, the velocity of light will be different inside it according as it travels with the stream or against it, and so the index of refraction will be different. Arago was the first to try this experiment, by placing an achromatic prism in front of a telescope on a mural circle, and observing the deviation it produced on stars.

Observe that it was an *achromatic* prism, treating all wave-lengths alike; he looked at the *deviated* image of a star, not at its *dispersed* image or spectrum, else he might have detected the change-of-frequency-effect due to motion of source or receiver first actually seen by Dr. Huggins. I do not think he would have seen it, because I do not suppose his arrangements were delicate enough for that very small effect; but there is no error in the conception of his experiment, as Prof. Mascart has inadvertently suggested there was.

Then Maxwell repeated the attempt in a much more powerful manner, a method which could have detected a very minute effect indeed, and Mascart has also repeated it in a simple form. All are absolutely negative.

Well, what about aberration? If one looks through a moving stratum, say a spinning glass disk, there ought to be a shift caused by the motion (see Fig. 4). The experiment has not been tried, but I entertain no doubt about its result, though a high speed and considerable thickness of glass or other medium is necessary to produce even a microscopic apparent displacement of objects seen through it.

But the speed of the earth is available, and the whole length of a telescope tube may be filled with water; surely that is enough to displace rays of light appreciably.

Sir Geo. Airy tried it at Greenwich on a star, with an appropriate zenith-sector full of water. Stars were seen through the water-telescope precisely as through an air telescope. A negative result again.

Stellar observations, however, are unnecessarily difficult. Fresnel had said that a terrestrial source of light would do just as well. He had also (being a man of exceeding genius) predicted that nothing would happen. Hoek has now tried it in a perfect manner and nothing did happen.

Since then Prof. Mascart with great pertinacity has attacked the phenomena of thick plates, Newton's rings, double refraction, and the rotatory phenomenon of quartz; but he has found absolutely nothing attributable to a stream of ether past the earth.

The only positive result ever supposed to be attained was in a very difficult polarization observation by Fizeau in 1859. As this has not yet been repeated, it is safest at present to ignore it, though by no means to forget that it wants repeating.

Fizeau also suggested, but did not attempt, what seems an easier experiment, with fore and aft thermopiles and a source between them, to observe the drift of a medium by its convection of energy; but arguments based on the law of exchanges[1] tend to show, and do show as I think, that a probable alteration of radiating power due to motion through a medium would just compensate the effect otherwise to be expected.

We may summarize most of these statements as follows:—

Summary.

Source alone moving produces	A real and apparent change of wave-length. A real but not apparent error in direction. No lag of phase or change of intensity, except that appropriate to altered wave-length.
Medium alone moving, or source and receiver moving together, produces	No change of frequency. No error in direction. A real lag of phase, but undetectable without control over the medium. A change of intensity corresponding to different distance, but compensated by change of radiating power.

---

[1] Lord Rayleigh (NATURE, March 25, 1892).

Receiver alone moving produces	An apparent change of wave-length. An apparent error in direction. No change of phase or of intensity, except that appropriate to different virtual velocity of light.

I may say, then, that not a single optical phenomenon is able to show the existence of an ether stream near the earth. All optics goes on precisely as if the ether were stagnant with respect to the earth.

Well then perhaps it *is* stagnant. The experiments I have quoted do not prove that it is so. They are equally consistent with its perfect freedom and with its absolute stagnation; though they are not consistent with any intermediate position. Certainly, if the ether were stagnant, nothing could be simpler than their explanation.

The only phenomena then difficult to explain would be those depending on light coming from distant regions through all the layers of more or less dragged ether. The theory of astronomical aberration would be seriously complicated; in its present form it would be upset. But it is never wise to control facts by a theory: it is better to invent some experiment that will give a different result in stagnant and in free ether. None of those experiments so far described are really discriminative. They are, as I say, consistent with either hypothesis, though not very obviously so.

Mr. Michelson, however, of the United States, has invented a plan that will discriminate; and, what is much more remarkable, he has carried it out.

That it is an exceptionally difficult experiment you will realize when I say that the experiment will fail altogether unless one part in 400 millions can be clearly detected.

Mr. Michelson reckons that by his latest arrangement he could see 1 in 4000 millions if it existed (which is equivalent to detecting an error of $\frac{1}{1000}$ of an inch in a length of forty miles); but he saw nothing. Everything behaved precisely as if the ether was stagnant; as if the earth carried with it all the ether in its immediate neighbourhood. And that is his conclusion. If he can repeat it and get a different result on the top of a mountain, that conclusion may be considered established. At present it must be regarded as tentative.

I have not time to go into the details of his experiment (it is described in *Phil. Mag.* 1887), but I may say that it depends on no doubtful properties of transparent substances, but on the straightforward fundamental principle underlying all such simple facts as that—It takes longer to row a certain distance and back up and down stream than it does to row the same distance in still water; or that it takes longer to run up and down a hill than to run the same distance laid out flat; or that it costs more to buy a certain number of oranges at three a penny and an equal number at two a penny than it does to buy the whole lot at five for twopence.

Hence, although there may be some way of getting round Mr. Michelson's experiment, there is no obvious way; and I conjecture that if the true conclusion be not that the ether near the earth is stagnant, the experiment will lead to some other important and unknown fact.

The balance of evidence at this stage seems to incline in the sense that the earth carries the neighbouring ether with it.

But now put the question another way. *Can* matter carry neighbouring ether with it when it moves? Abandon the earth altogether; its motion is very quick, but too uncontrollable, and it always gives negative results. Take a lump of matter that you can deal with, and see if it pulls any ether along.

That is the experiment I set myself to perform, and which, in the course of the last year, I have performed.

I take a steel disk, or rather a couple of steel disks clamped together with a space between. I mount it on a vertical axis and spin it like a teetotum as fast as it will stand without flying to pieces. Then I take a parallel beam of light, split it into two by a semi-transparent mirror (Michelson's method), a piece of glass silvered so thinly that it lets half the light through and reflects the other half; and I send the two halves of this split beam round and round in opposite directions in the space between the disks. They may thus travel a distance of 20 or 30 or 40 feet. Ultimately they are allowed to meet and enter a telescope. If they have gone quite identical distances they need not interfere, but usually the distances will differ by a hundred-thousandth of an inch or so, which is quite enough to bring about interference.

The mirrors which reflect the light round and round between the disks are shown in Fig. 10. If they form an accurate square the last two images will coincide, but if the mirrors are the least inclined to one another at any unaliquot part of 360° the last image splits into two, as in the kaleidoscope is well known, and the interference bands may be regarded as resulting from those two sources. The central white band bisects normally the distance between them, and their amount of separation determines the width of the bands. There are many interesting optical details here, but I shall not go into them.

The thing to observe is whether the motion of the disks is able to replace a bright band by a dark one, or *vice versâ*. If it does, it means that one of the half beams, viz. that which is travelling in the same direction as the disks, is helped on a trifle, equivalent to a shortening of journey by some quarter millionth of an inch or so in the whole length of 30 feet; while the other half beam, viz., that travelling against the motion of the disks, is retarded, or its path virtually lengthened, by the same amount.

If this acceleration and retardation actually occurs, waves which did not interfere on meeting before the disks moved, will interfere now, for one will arrive at the common goal half a length behind the other.

Now a gradual change of bright space to dark, and *vice versâ*, shows itself, to an observer looking at the bands, as a gradual change of position of the bright stripes, or a shift of the bands. A shift of the bands, and especially of the middle white band, which is much more stable than the others, is what we look for.

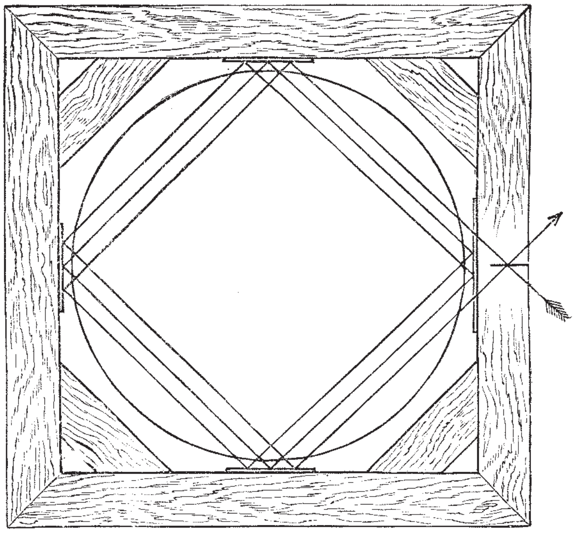

FIG. 10.—Plan of steel disks one yard in diameter, and optical frame; showing the light going round and round, three times each way, between the disks.

At first I saw plenty of shift. In the first experiment the bands sailed across the field as the disks got up speed until the crosswire had traversed a band and a half. The conditions were such that had the ether whirled at the full speed of the disks I should have seen a shift of three bands. It looked very much as if the light was helped along at half the speed of the moving matter, just as it is inside water.

On stopping the disks the bands returned to their old position. On starting them again in the opposite direction, the bands ought to have shifted the other way too; but they did not; they went the same way as before.

The shift was therefore wholly spurious; it was caused by the centrifugal force of the blast of air thrown off from the moving disks. The mirrors and frame had to be protected from this. Many other small changes had to be made, and gradually the spurious shifts have been reduced and reduced, largely by the skill and patience of my assistant, Mr. Davies, until now there is barely a trace of them.

But the experiment is not an easy one. Not only does the blast exert pressure, but at high speeds the churning of the air makes it quite hot. Moreover, the tremor of the whirling machine, in which some four or five horse-power is sometimes being expended, is but too liable to communicate itself to the optical part of the apparatus. Of course elaborate precautions are taken against this. Although the two parts, the mechanical and the optical, are so close together, their supports are entirely independent. But they have to rest on the same earth, and hence communicated tremors are not absent. They are the cause of all the slight residual trouble.

The method of observation now consists in setting a wire of the micrometer accurately in the centre of the middle band, while another wire is usually set on the first band to the left. Then the micrometer heads are read, and the setting repeated once or twice to see how closely and dependably they can be set in the same position. Then we begin to spin the disks, and when they are going at some high speed, measured by a siren note and in other ways, the micrometer wires are reset and read—reset several times and read each time. Then the disks are stopped and more readings are taken. Then their motion is reversed, the wires set and read again; and finally the motion is once more stopped and another set of readings taken. By this means the absolute shift of middle band and its relative interpretation in terms of wave-length are simultaneously obtained; for the distance from the one wire to the other, which is often two revolutions of a micrometer head, represents a whole wave-length shift.

In the best experiments I do still often see something like a fiftieth of a band shift, but it is caused by residual spurious causes, for it repeats itself with sufficient accuracy in the same direction when the disks are spun the other way round.

Of real reversible shift, due to motion of the ether, I see nothing. I do not believe the ether moves. It does not move at a five-hundredth part of the speed of the steel disks. I hope to go further, but my conclusion so far is that such things as circular-saws, flywheels, railway trains, and all ordinary masses of matter do not appreciably carry the ether with them. Their motion does not seem to disturb it in the least.

The presumption is that the same is true for the earth; but the earth is a big body, it is conceivable that so great a mass may be able to act when a small mass would fail. I would not like to be too sure about the earth. What I do feel already pretty sure of is that if moving matter disturbs ether in its neighbourhood at all, it does so by some minute action, comparable in amount perhaps to gravitation, and possibly by means of the same property as that to which gravitation is due—not by anything that can fairly be likened to ethereal viscosity.

NATIVE NEW ZEALAND BIRDS.

FROM a scientific point of view it is of so much importance that native New Zealand birds should be protected that many naturalists will read with interest the following memorandum, which was drawn up by Lord Onslow, the late Governor of New Zealand, and presented to both Houses of the General Assembly by command of his Excellency:—

It is admitted by naturalists that New Zealand possesses in some respects the most interesting avifauna in the world. It is a melancholy fact that, under the changed condition of existence this remarkable avifauna is passing away. Some of the species have already disappeared, whilst others are verging on extinction. Take, for example, the wingless birds of New Zealand. These diminutive representatives of the gigantic brevipennate birds which formerly inhabited New Zealand are objects of the highest interest to the natural historian. The kiwis, like their colossal prototypes the moas, once existed in very considerable numbers in almost every part of the country. At the time of the first colonization of New Zealand, fifty years ago, they were still abundant in all suitable localities. At the present day their last refuges may be indicated on the map without any difficulty. The North Island species (*Apteryx bulleri*) is still comparatively plentiful in the wooded heights of Pirongia and in the bosky groves of the Upper Wanganui. From all other localities where formerly numerous it has practically disappeared. The South Island kiwi (*Apteryx australis*) is now met with in only widely-scattered localities on the west coast. The small spotted or grey kiwi (*Apteryx oweni*), of which perhaps thousands could have been obtained a few years back, has succumbed to the ravages of the stoat and weasel, the persecution by wild dogs, and the necessities of roving diggers, and it is only now to be found in any number along the lower wooded ranges of the Southern Alps. *Apteryx haasti* is one of our rarest species, and *Apteryx maxima* is strictly confined to the wooded parts of Stewart Island.

The kakapo, or ground-parrot (*Stringops habroptilus*), which was formerly so abundant in the wooded country along the whole of the West Coast Sounds and on the western slope of the Southern Alps, is becoming a scarce bird. According to Mr. Richardson, who recently read an exhaustive paper on the subject before the Otago Institute, both the kiwi and the kakapo are now confined to very restricted districts, within which, under the combined attacks of introduced wild dogs and cats, stoats, weasels, and ferrets, they are fast diminishing.

The blue-wattled crow and South Island thrush, which were every-day camp-visitors when Sir James Hector explored the West Coast in 1863, are now very rarely seen; whilst in the North Island the native thrush and some of the smaller birds have disappeared altogether.

Prominent writers on zoological science, such as Prof. Newton, of Cambridge, Prof. Flower, at the head of the British Museum, and Dr. Sclater, the accomplished secretary of the Zoological Society of London, have over and over again urged the importance of some steps being taken for the conservation of New Zealand birds; and they have pointed out that it will be a lasting reproach to the present generation of colonists if no attempt is made to save some—if only a remnant—of these expiring forms for the student of the future. Thus, Prof. Newton, in his address to the Biological Section of the British Association, at Manchester, in 1887, saith: "I would ask you to bear in mind that these indigenous species of New Zealand are, with scarcely an exception, peculiar to the country, and, from every scientific point of view, of the most instructive character. They supply a link with the past that, once lost, can never be recovered. It is therefore incumbent upon us to know all we can about them before they vanish. . . . The forms we are allowing to be killed off, being almost without exception ancient forms, are just those that will teach us more of the way in which life has spread over the globe than any other recent forms; and for the sake of posterity, as well as to escape its reproach, we ought to learn all we can about them before they go hence and are no more seen."

The chief cause of the destruction of native birds is no doubt the introduction of foreign animals, against which the indigenous species are unable to contend successfully in the struggle for existence, especially under the changed conditions of life brought about by colonization. Probably the chief factor in this work of destruction is the Norway rat, whose introduction was of course unintentional, but an inevitable incident of settlement. The insectivorous and other birds introduced (whether wisely or not it is not necessary now to discuss) by our various acclimatization societies have, as it were, driven out and replaced many of the native species. These latter have succumbed to some general law of nature under which races of animals and plants yield to foreign invasion and rapidly disappear, the aboriginal races of man being no exception to this general rule. Where the causes themselves are recondite, it is, of course, difficult to find the means of counteracting them; but it is an observed law of nature that expiring races survive and linger longest in insular areas. That has been the experience of zoologists all over the world, the islands of Mauritius and Rodriguez presenting a striking instance in point. Here in New Zealand we have many similar evidences. The remarkable tuatara lizard (*Sphenodon punctatum*), supposed to be a survival from a very ancient fauna, and constituting, *per se*, a distinct order of reptilia, which years ago became extinct on the mainland (chiefly through the ravages of introduced wild pigs), still exists in very considerable numbers on the small islands lying off our coasts. The mako-mako, or bell-bird (*Anthornis melanura*), at one time the very commonest of our birds, although still plentiful in the South Island, has absolutely disappeared from every part of the North Island, but it still exists on the wooded islands of the Hauraki Gulf and Bay of Plenty, and on the island of Kapiti, in Cook Strait. The same remarks apply with almost equal force to the wood-robin (*Miro albifrons*) and the white-head (*Clitonyx albicapilla*), two species which have never inhabited the South Island at all. The stitch-bird (*Pogonornis cincta*), which forms a sort of connecting link with the avifauna of Australia, was thirty years ago very plentiful in the woods surrounding Wellington, but it had long before disappeared from the northern parts of the island. It is now